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APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
10/526,225	02/08/2006	Yoshikazu Kakura	Q86499	6775

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EXAMINER	
NGUYEN, LEON VIET Q	

ART UNIT	PAPER NUMBER
2611	

MAIL DATE	DELIVERY MODE
05/07/2009	PAPER

Please find below and/or attached an Office communication concerning this application or proceeding.

The time period for reply, if any, is set in the attached communication.

Office Action Summary	Application No.	Applicant(s)	
	10/526,225	KAKURA ET AL.	
	Examiner	Art Unit	
	LEON-VIET Q. NGUYEN	2611	

-- *The MAILING DATE of this communication appears on the cover sheet with the correspondence address* --

Period for Reply

A SHORTENED STATUTORY PERIOD FOR REPLY IS SET TO EXPIRE 3 MONTH(S) OR THIRTY (30) DAYS, WHICHEVER IS LONGER, FROM THE MAILING DATE OF THIS COMMUNICATION.

- Extensions of time may be available under the provisions of 37 CFR 1.136(a). In no event, however, may a reply be timely filed after SIX (6) MONTHS from the mailing date of this communication.
- If NO period for reply is specified above, the maximum statutory period will apply and will expire SIX (6) MONTHS from the mailing date of this communication.
- Failure to reply within the set or extended period for reply will, by statute, cause the application to become ABANDONED (35 U.S.C. § 133). Any reply received by the Office later than three months after the mailing date of this communication, even if timely filed, may reduce any earned patent term adjustment. See 37 CFR 1.704(b).

Status

1)☒ Responsive to communication(s) filed on *25 February 2009*.

2a)☒ This action is **FINAL**. 2b)☐ This action is non-final.

3)☐ Since this application is in condition for allowance except for formal matters, prosecution as to the merits is closed in accordance with the practice under *Ex parte Quayle*, 1935 C.D. 11, 453 O.G. 213.

Disposition of Claims

4)☒ Claim(s) *1-8* is/are pending in the application.

4a) Of the above claim(s) _____ is/are withdrawn from consideration.

5)☐ Claim(s) _____ is/are allowed.

6)☒ Claim(s) *1-8* is/are rejected.

7)☐ Claim(s) _____ is/are objected to.

8)☐ Claim(s) _____ are subject to restriction and/or election requirement.

Application Papers

9)☐ The specification is objected to by the Examiner.

10)☒ The drawing(s) filed on *01 March 2005* is/are: a)☐ accepted or b)☐ objected to by the Examiner.

Applicant may not request that any objection to the drawing(s) be held in abeyance. See 37 CFR 1.85(a).

Replacement drawing sheet(s) including the correction is required if the drawing(s) is objected to. See 37 CFR 1.121(d).

11)☐ The oath or declaration is objected to by the Examiner. Note the attached Office Action or form PTO-152.

Priority under 35 U.S.C. § 119

12)☒ Acknowledgment is made of a claim for foreign priority under 35 U.S.C. § 119(a)-(d) or (f).

a)☒ All b)☐ Some * c)☐ None of:

1.☒ Certified copies of the priority documents have been received.

2.☐ Certified copies of the priority documents have been received in Application No. _____.

3.☐ Copies of the certified copies of the priority documents have been received in this National Stage application from the International Bureau (PCT Rule 17.2(a)).

* See the attached detailed Office action for a list of the certified copies not received.

Attachment(s)

1) ☒ Notice of References Cited (PTO-892)

2) ☐ Notice of Draftsperson's Patent Drawing Review (PTO-948)

3) ☐ Information Disclosure Statement(s) (PTO/SB/08) Paper No(s)/Mail Date _____.

4) ☐ Interview Summary (PTO-413) Paper No(s)/Mail Date. _____ .

5) ☐ Notice of Informal Patent Application

6) ☐ Other: _____.

DETAILED ACTION

1. This office action is in response to communication filed on 2/25/09. Claim 8 has been added. Claims 1-8 are pending on this application.

Response to Arguments

2. Applicant's arguments filed 2/25/09 have been fully considered but they are not persuasive.

Response to Remarks

Regarding claim 1, applicant asserts that the teaching of Xiao is different from claim 1 in that claim 1 recites spreading codes that are used in communication so as to be orthogonal on the frequency and/or time axis whereas Xiao describe Walsh codes on the frequency axis are multiplied by Walsh codes on the time axis yielding two-dimensional orthogonal codes (Remarks page 5 last paragraph).

Examiner respectfully disagrees.

It is first noted that Walsh codes are well known in the art to be used as spreading codes. Xiao was relied up to teach spreading codes which are orthogonal at least in only N chips on the time axis and/or in only M chips on the frequency axis (page 1224 right side second paragraph).

In response to applicant's argument that the references fail to show certain features of applicant's invention, it is noted that the features upon which applicant relies (i.e., adaptively assigning despreading codes by considering fluctuation of propagation

paths on the frequency and time axis) are not recited in the rejected claim(s). Although the claims are interpreted in light of the specification, limitations from the specification are not read into the claims. See *In re Van Geuns*, 988 F.2d 1181, 26 USPQ2d 1057 (Fed. Cir. 1993).

Also regarding claim 1, applicant asserts that modifying the background of the specification with Xiao would render the system inoperable for its intended purpose (Remarks page 6 second paragraph).

Examiner respectfully disagrees.

In response to applicant's argument, the test for obviousness is not whether the features of a secondary reference may be bodily incorporated into the structure of the primary reference; nor is it that the claimed invention must be expressly suggested in any one or all of the references. Rather, the test is what the combined teachings of the references would have suggested to those of ordinary skill in the art. See *In re Keller*, 642 F.2d 413, 208 USPQ 871 (CCPA 1981).

Additionally, applicant asserts that there is no motivation to combine the background and Xiao (Remarks page 7 second paragraph).

Examiner respectfully disagrees.

In response to applicant's argument that there is no suggestion to combine the references, the examiner recognizes that obviousness can only be established by combining or modifying the teachings of the prior art to produce the claimed invention

where there is some teaching, suggestion, or motivation to do so found either in the references themselves or in the knowledge generally available to one of ordinary skill in the art. See *In re Fine*, 837 F.2d 1071, 5 USPQ2d 1596 (Fed. Cir. 1988)and *In re Jones*, 958 F.2d 347, 21 USPQ2d 1941 (Fed. Cir. 1992). In this case, the use of orthogonality may not increase the capacity of the conventional system of the background. However it is well known in the art that Walsh codes provide orthogonal spreading in such a way that only the receiver with the same code can recover it. This utilization of orthogonality significantly reduces interference between signals.

Furthermore, applicant asserts that using orthogonality to reduce interference between signals would not be sufficient to show obviousness since a solution would fail to account for fluctuation on the frequency or time axis (Remarks page 8 first paragraph).

In response to applicant's argument that the references fail to show certain features of applicant's invention, it is noted that the features upon which applicant relies (i.e., accounting for fluctuation on the frequency or time axis) are not recited in the rejected claim(s). Although the claims are interpreted in light of the specification, limitations from the specification are not read into the claims. See *In re Van Geuns*, 988 F.2d 1181, 26 USPQ2d 1057 (Fed. Cir. 1993).

Regarding claim 3, applicant asserts that the combination of the background, Xiao, and Uesugi would not be obvious because it would be using the function of

Uesugi for a purpose other than what it was intended for (Remarks page 10 first paragraph).

Examiner respectfully disagrees.

The purpose of Uesugi is to maintain orthogonality of codes even when spreading factors are different (¶0055 of Uesugi). This is achieved by monitoring the fluctuation of the time axis direction (¶0054 of Uesugi). Uesugi was relied upon in the previous office action to teach the limitation in claim 3 of "detecting whether *either* of channel fluctuation on the frequency axis of *channel fluctuation on the time axis* is prominent". Xiao was relied upon to teach assigning orthogonal spreading codes (see the previous office action). However Uesugi teaches assigning two-dimensional spreading codes (¶0050 of Uesugi) in which the codes are orthogonal (¶0051 of Uesugi). The assigning of orthogonal spreading codes taught by Uesugi is similar to the language recited in claim 3 of the current application and therefore interpreted to be obvious. Furthermore, Xiao was not relied upon to teach assigning codes based on channel fluctuation. Uesugi was relied upon to teach that limitation.

Claim Rejections - 35 USC § 103

1. The following is a quotation of 35 U.S.C. 103(a) which forms the basis for all obviousness rejections set forth in this Office action:

> (a) A patent may not be obtained though the invention is not identically disclosed or described as set forth in section 102 of this title, if the differences between the subject matter sought to be patented and the prior art are such that the subject matter as a whole would have been obvious at the time the invention was made to a person having ordinary skill in the art to which said subject matter pertains. Patentability shall not be negatived by the manner in which the invention was made.

2. Claims 1, 2, 7 and 8 are rejected under 35 U.S.C. 103(a) as being unpatentable over the background of applicant's specification (hereby referred to as the background) in view of Xiao et al ("A Novel MC-2D-CDMA Communication Systems and Its Detection Methods" 2000 IEEE International Conference on Communications, Publication Date: 2000 Volume: 3, On page(s): 1223-1227).

Re claim 1, the background teaches a radio transmitter-receiver wherein a pilot symbol that has undergone M-chip spreading on a frequency axis (the vertical axis in fig. 2) and N-chip spreading on a time axis (the horizontal axis in fig. 2) by means of a spreading code having an M x N chip length (page 3 line 26 – page 4 line 2) where M and N are any integers greater than or equal to 2 (fig. 2, page 3 line 26 – page 4 line 2) is used in the transmitter (it is well known that spreading codes are used in the transmitter portion of a system), and in the receiver, a spreading code that is not used in spreading a pilot signal is used as a despreading code to despread a received signal and then estimate noise and interference power (page 2 lines 18-21. One of ordinary skill in the art would have found it obvious to implement CDMA techniques in a MC-2D-CDMA system, which is based on CDMA).

The background fails to teach wherein said spreading code that is used in spreading a pilot symbol and said despreading code that is used in despreading are assigned so as to be orthogonal at least in only N chips on the time axis and/or in only M chips on the frequency axis. However Xiao teaches spreading codes which are orthogonal at least in only N chips on the time axis and/or in only M chips on the frequency axis (page 1224 right side second paragraph).

Therefore taking the combined teachings of the background and Xiao as a whole, it would have been obvious to one of ordinary skill in the art at the time the invention was made to incorporate the feature of Xiao into the apparatus of the background. The motivation to combine Xiao and the background would be to provide higher capacity (page 1223 left side third paragraph of Xiao). Furthermore it is well know that utilizing orthogonality reduces interference between signals.

Re claim 2, the modified invention of the background teaches a radio transmitter-receiver wherein at least one of code that is orthogonal to said despreading code that is used in despreading even if only in M chips on the frequency axis and/or code that is orthogonal to said despreading code that is used in despreading even if only in N chips on the time axis (page 1224 right side second paragraph of Xiao) is preferentially assigned as said spreading code that is used in spreading pilot symbols (page 1224 right side second paragraph of Xiao. The Walsh code is a spreading code).

Re claim 7, all of the claim limitations as recited have been analyzed and addressed in the above rejections with respect to claim 1. It would be obvious and necessary to have a method of using the apparatus as claimed in claim 1.

Re claim 8, the modified invention of the background teaches a radio transmitter-receiver wherein the spreading code is at least one of a plurality of orthogonal spreading codes (page 1224 right side second paragraph of Xiao. The two dimensional

orthogonal spreading code is realized by multiplying the codes on the time and frequency axis. Since there may be a different code on the frequency axis, it is interpreted that there is more than one orthogonal spreading code).

3. **Claims 3 and 4 are rejected under 35 U.S.C. 103(a) as being unpatentable over the background of applicant's specification (hereby referred to as the background) and Xiao et al ("A Novel MC-2D-CDMA Communication Systems and Its Detection Methods" 2000 IEEE International Conference on Communications, Publication Date: 2000 Volume: 3, On page(s): 1223-1227) in view of Uesugi et al (US20040042386).**

Re claim 3, the modified invention of the background fails to teach a radio transmitter-receiver comprising:

means for detecting whether either of channel fluctuation on the frequency axis or channel fluctuation on the time axis is prominent; wherein:

code that is orthogonal even if only in M chips on the frequency axis is assigned as said spreading code that is used in spreading a pilot symbol when channel fluctuation is prominent on the time axis; and

code that is orthogonal even if only in N chips on the time axis is assigned as said spreading code that is used in spreading a pilot symbol when channel fluctuation is prominent on the frequency axis.

However Uesugi teaches detecting whether either of channel fluctuation on the frequency axis or channel fluctuation on the time axis is prominent (¶0051, ¶0054. The symbol portion of the frequency and time axis is maximum. Reduced orthogonality of time axis direction under intensive time fluctuation) wherein:

code that is orthogonal even if only in M chips on the frequency axis is assigned as said spreading code that is used in spreading a pilot symbol (page 1224 right side second paragraph of Xiao) when channel fluctuation is prominent on the time axis (¶0051. The symbol portion of the time axis is maximum); and

code that is orthogonal even if only in N chips on the time axis is assigned as said spreading code that is used in spreading a pilot symbol (page 1224 right side second paragraph of Xiao) when channel fluctuation is prominent on the frequency axis (¶0051. The symbol portion of the time axis is maximum).

Therefore taking the modified teachings of the background and Xiao with Uesugi as a whole, It would have been obvious to one of ordinary skill in the art at the time the invention was made to incorporate the feature of Uesugi into the apparatus of the background and Xiao. The motivation to combine the background, Xiao, and Uesugi would be to optimize the axis direction of every code while maintaining orthogonality (¶0054 of Uesugi).

Re claim 4, the modified invention of the background teaches a radio transmitter-receiver wherein delay spread is used as an index of channel fluctuation on the frequency axis (¶0054 of Uesugi, the long delay wave is interpreted to be a delay spread).

4. Claim 5 is rejected under 35 U.S.C. 103(a) as being unpatentable over the background of applicant's specification (hereby referred to as the background), Xiao et al ("A Novel MC-2D-CDMA Communication Systems and Its Detection Methods" 2000 IEEE International Conference on Communications, Publication Date: 2000 Volume: 3, On page(s): 1223-1227) and Uesugi et al (US20040042386) in view of Sudo (US20040071078).

Re claim 5, the modified invention of the background fails to teach a radio transmitter-receiver wherein a coherent band is used as an index of channel fluctuation on the frequency axis.

However Sudo teaches wherein a coherent band is used as an index of channel fluctuation (¶0423, the coherent detection is interpreted to correspond to a coherent band) on the frequency axis (¶0431).

Therefore taking the modified teachings of the background, Xiao, and Uesugi with Sudo as a whole, It would have been obvious to one of ordinary skill in the art at the time the invention was made to incorporate the feature of Sudo into the apparatus of the background, Xiao, and Uesugi. The motivation to combine the background, Xiao,

Sudo and Uesugi would be to improve the error rate characteristic with almost no lowering of transfer efficiency (¶0424 of Sudo).

5. Claim 6 rejected under 35 U.S.C. 103(a) as being unpatentable over the background of applicant's specification (hereby referred to as the background), Xiao et al ("A Novel MC-2D-CDMA Communication Systems and Its Detection Methods" 2000 IEEE International Conference on Communications, Publication Date: 2000 Volume: 3, On page(s): 1223-1227) and Uesugi et al (US20040042386) in view of Sumasu et al (US20040028007).

Re claim 6, the modified invention of the background fails to teach a radio transmitter-receiver wherein Doppler frequency is used as an index of channel fluctuation on the time axis.

However Sumasu teaches wherein Doppler frequency is used as an index of channel fluctuation (page 7, claim 8) on the time axis (page 6, claim 1).

Therefore taking the modified teachings of the background, Xiao, and Uesugi with Sumasu as a whole, It would have been obvious to one of ordinary skill in the art at the time the invention was made to incorporate the feature of Sumasu into the apparatus of the background, Xiao, and Uesugi. The motivation to combine the background, Xiao, Sumasu and Uesugi would be to minimize the occurrence of burst errors (¶0026 of Sumasu).

Conclusion

6. **THIS ACTION IS MADE FINAL.** Applicant is reminded of the extension of time policy as set forth in 37 CFR 1.136(a).

A shortened statutory period for reply to this final action is set to expire THREE MONTHS from the mailing date of this action. In the event a first reply is filed within TWO MONTHS of the mailing date of this final action and the advisory action is not mailed until after the end of the THREE-MONTH shortened statutory period, then the shortened statutory period will expire on the date the advisory action is mailed, and any extension fee pursuant to 37 CFR 1.136(a) will be calculated from the mailing date of the advisory action. In no event, however, will the statutory period for reply expire later than SIX MONTHS from the mailing date of this final action.

Any inquiry concerning this communication or earlier communications from the examiner should be directed to LEON-VIET Q. NGUYEN whose telephone number is (571)270-1185. The examiner can normally be reached on Monday-Friday, alternate Friday off, 7:30AM-5PM.

If attempts to reach the examiner by telephone are unsuccessful, the examiner's supervisor, David C. Payne can be reached on 571-272-3024. The fax phone number for the organization where this application or proceeding is assigned is 571-273-8300.

Information regarding the status of an application may be obtained from the Patent Application Information Retrieval (PAIR) system. Status information for published applications may be obtained from either Private PAIR or Public PAIR. Status information for unpublished applications is available through Private PAIR only. For more information about the PAIR system, see http://pair-direct.uspto.gov. Should you have questions on access to the Private PAIR system, contact the Electronic Business Center (EBC) at 866-217-9197 (toll-free). If you would like assistance from a USPTO Customer Service Representative or access to the automated information system, call 800-786-9199 (IN USA OR CANADA) or 571-272-1000.

/Leon-Viet Q Nguyen/
Examiner, Art Unit 2611

/Kevin M. Burd/
Primary Examiner, Art Unit 2611

Notice of References Cited	Application/Control No. 10/526,225	Applicant(s)/Patent Under Reexamination KAKURA ET AL.	
	Examiner LEON-VIET Q. NGUYEN	Art Unit 2611	Page 1 of 1

U.S. PATENT DOCUMENTS

*		Document Number Country Code-Number-Kind Code	Date MM-YYYY	Name	Classification
*	A	US-2004/0028007 A1	02-2004	Sumasu et al.	370/320
*	B	US-2004/0042386 A1	03-2004	Uesugi et al.	370/204
*	C	US-2004/0071078 A1	04-2004	Sudo, Hiroaki	370/208
	D	US-			
	E	US-			
	F	US-			
	G	US-			
	H	US-			
	I	US-			
	J	US-			
	K	US-			
	L	US-			
	M	US-			

FOREIGN PATENT DOCUMENTS

*		Document Number Country Code-Number-Kind Code	Date MM-YYYY	Country	Name	Classification
	N					
	O					
	P					
	Q					
	R					
	S					
	T					

NON-PATENT DOCUMENTS

*		Include as applicable: Author, Title Date, Publisher, Edition or Volume, Pertinent Pages)
	U	Xiao et al ("A Novel MC-2D-CDMA Communication Systems and Its Detection Methods" 2000 IEEE International Conference on Communications, Publication Date: 2000 Volume: 3, On page(s): 1223-1227)
	V	
	W	
	X	

*A copy of this reference is not being furnished with this Office action. (See MPEP § 707.05(a).)
Dates in MM-YYYY format are publication dates. Classifications may be US or foreign.

A Novel MC-2D-CDMA Communication Systems and Its Detection Methods

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Abstract-This paper presents a novel multicarrier-2-Dimension-code division multiple access (MC-2D-CDMA) system for forward link. Because of the full utilization of 2-Dimension spreading characteristic, the ability to reject fading and multiple access interference (MAI) is enhanced. For this system, we examine some diversity combination methods. Among them, Weighted Least Square Combination (WLSC) has better performance but is not very suitable for forward link; Auxiliary Vector Combination (AVC), the combination of Maximum Ratio Combination (MRC) and Orthogonality Restoring Correlation (ORC) is very simple and robust, and very suitable for forward link because it does not require any prior knowledge about other users and noise. The simulation results show their validity to anti-fading and anti-MAI.

I. INTRODUCTION

Recently, the multicarrier modulation scheme, or orthogonal frequency-division multiplexing (OFDM) has drawn a lot of attention because of its anti-fading capability and the need to transmit high data rate. By using the fast Fourier transform (FFT) and inverse transform (IFFT), the multicarrier scheme not increases the complexities but achieve high spectral efficiency.

To provide higher capacity, the combination of multicarrier and code division multiple access (CDMA) is also developed[2]. According to their multiple access characteristics, these systems can be categorized into two types, spreading and multiple access in the frequency field, called MC-CDMA[3]-[5], or spreading and multiple access in the time field, called Multicarrier DS-CDMA[6][7]. In the former system, a spreading sequence is serial-to-parallel converted and modulates different carriers, and different users utilize different spreading codes in the frequency field. In the latter system, each carrier is used to transmit a narrowband DS waveform, and different users utilize different spreading codes in the time field.

This paper presents a novel MC-2D-CDMA system for forward link. In this system, spreading and multiple access are carried out both in the frequency field and in the time field. Compared with MC-CDMA, MC-2D-CDMA has better anti-MAI capability due to spreading in the time field. Compared with Multicarrier DS-CDMA, MC-2D-CDMA has better anti-fading capability due to frequency diversity resulting from spreading in the frequency field. Because of the full utilization of 2-Dimension spreading characteristic, the capability of multi-access is increased greatly and the frequency diversity provides anti-fading ability.

In the MC-2D-CDMA system, two spreading sequences are used, one in the frequency field and the other in the time field. Some users are discriminated by different spreading codes in the time field, and others are discriminated by different spreading codes in the frequency field. For the former, the simple matched filter can distinguish them very well because the orthogonality between spreading codes are maintained due to frequency-nonselective fading in each carrier. For the latter, many detection schemes for MC-CDMA, such as MRC, ORC, EGC, MLD, MMSEC, MUD and so on[1], are also suitable to distinguish these users. However, due to multiple access interference (MAI), conventional detection schemes, such as MRC and EGC, perform not well, while performancewise detection schemes, such as MLD, MMSEC and MUD, require the prior knowledge about other users and are usually very complex. So, for this system, we present and examine some new diversity combination methods. Among them, WLSC and MMSEC have better performance since they consider the signal and interference comprehensively. However they require the knowledge about other users' signal, which is an unrealistic requirement for forward link, and their complexity increase greatly with the increase of the number of users and the number of carriers. We also provide simpler approximating algorithm for them. Moreover, for decreasing the complexity further, we present Auxiliary Vector Combination (AVC), the combination of Maximum Ratio Combination (MRC) and Orthogonality Restoring Correlation (ORC). Due to the good anti-fading capability of MRC and good anti-MAI capability of ORC, the AVC receiver has great capability to reject both fading and MAI, but avoids their drawbacks. Moreover, AVC is very simple and robust, and very suitable for forward link because it does not require any prior knowledge about other users and noise.

This paper firstly presents system description in section II including channel model, transmitter model and receiver model. Then we examine some diversity combination methods in section III and verify their performances by simulation in section IV. Finally conclusions are presented in section V.

II. SYSTEM DESCRIPTION

A. Channel Model

* This work was finished when the author was studying for doctor degree in Peking University

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As a Rayleigh fading channel, we assume a wide sense stationary uncorrelated scattering (WSSUS) channel[9] with impulse response

$$h(\tau;t)=\sum_{l=1}^{L} g_l(t)\delta(\tau-\tau_l).$$

Here, t and τ are the time and delay respectively. $\delta(\cdot)$ is the Dirac delta function and $g_l(t)$ is the lth path gain, which is a mutually independent complex Gaussian random process.

According to the multipath channel model, we can achieve the coherence bandwidth, $(\Delta f)_c$, to measure the frequency coherence of the channel and coherence time, $(\Delta t)_c$, to measure the time coherence of the channel.

B. Transmitter Model

The transmitter model of the MC-2D - CDMA system is shown in Fig. 1.

In this figure, b_k, the data stream for the k^{th} user, is firstly multiplied by spreading code c_k with spreading ratio M. The spreaded sequences are S/P converted by $1{:}M$ and sent to various carriers. Each signal in various carriers is multiplied by spreading code a_k with spreading ratio N. In the MC-2D - CDMA system, following conditions should be satisfied,

- The carrier frequencies should be orthogonal, that is, $\omega_m=\omega_0+2\pi\frac{(m-1)P}{T_c}$. ω_0 is the lowest carrier frequency and $1/T_c$ is chip rate in any carrier. P is an integral parameter that makes the carrier separation greater than $(\Delta f)_c$, the coherence bandwidth of the multi-path channel, so that the fading in different carriers is independent.
- The signal bandwidth of each carrier, about $2/T_c$, should be less than $(\Delta f)_c$ so that the fading in each carrier is frequency non-selective.
- The bit period in each carrier, $1/NT_c$, should be much less than $(\Delta t)_c$, the coherence time of the multi-path channel, so that the fading in each carriers is slow.

For meeting these conditions, the interleaver should be added, but for the convenience, they are omitted in the Fig. 1 and following discussion. So, the transmission signal for the k^{th} user can be expressed by

$$s_k(t)=\sum_{m=1}^{M}\left[\sum_{n=1}^{N}\sqrt{2E}b_k c_k(m)a_k(n)g(t-nT_c)\right]\cos(\omega_m t)\cdot \quad (1)$$

Here, E is transmitted energy of single carrier; $g(t)$ is rectangle function during $[0,T_c]$; c_k is spreading code in the frequency field; a_k is spreading code in the time field.

So, the total transmission signal for K users in forward link is

$$\begin{aligned} s(t)&=\sum_{k=1}^{K}s_k(t) \\ &=\sum_{m=1}^{M}\left[\sum_{n=1}^{N}\sqrt{2E}\sum_{k=1}^{K}b_k c_k(m)a_k(n)g(t-nT_c)\right]\cos(\omega_m t)\end{aligned} \quad . \quad (2)$$

For making the codes orthogonal in the time field and frequency field, we adopt c_k as WALSH codes of period M and a_k as WALSH codes of period N. So the maximum number of users is $M\times N$. For convenience, we can allocate codes for various users according their series number. For example, the signal for user k is spreaded both by WALSH code of period N with series number (k *mod* N) in the time field, and by WALSH code of period M with series number (k *div* M) in the frequency field. So we can divide all the users into N groups according to their spreading code in the time field: the users in the same group, where (k *mod* N) is equal, have same spreading code in the time field and different spreading code in the frequency field. So the maximum number of users in a group is M.

C. Receiver Model

According to the transmission signal above, we can derive the receiver model of user k as shown in Fig. 2.

In this figure, the received signal is

$$\begin{aligned} r(t)&=n(t)+\int_{-\infty}^{+\infty}s(t-\tau)\otimes h(\tau;t)d\tau \\ &=n(t)+ \\ &\sum_{m=1}^{M}\left[\sum_{n=1}^{N}\alpha_m\sum_{k=1}^{K}b_k c_k(m)a_k(n)g(t-nT_c)\right]\cos(\omega_m t+\psi_m)\end{aligned} \quad (3)$$

Here, α_m and ψ_m are the amplitude and phase of received signal in different carriers through different fading, and their distributions are Rayleigh and uniform respectively. Because of the assuming of slow fading, α_m and ψ_m are constant in a bit duration in (3). $n(t)$ is additive white Gaussian noise (AWGN) with a single-sided power spectral density of N_0.

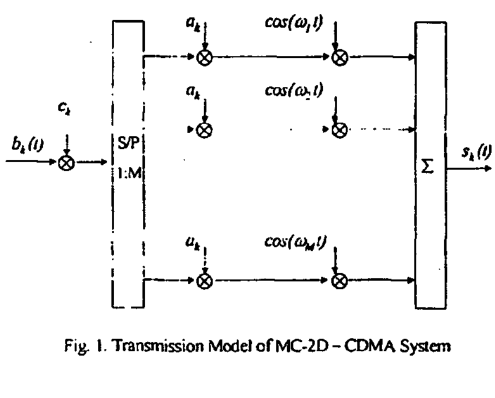

Fig. 1. Transmission Model of MC-2D - CDMA System

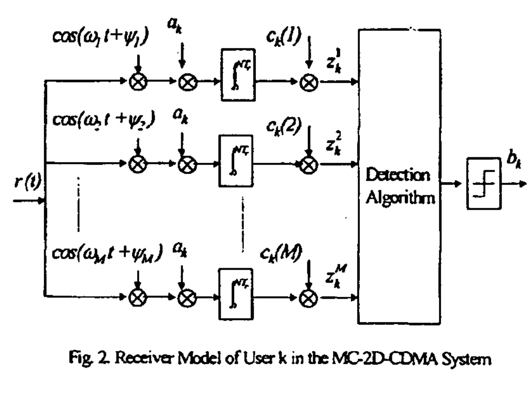

Fig. 2. Receiver Model of User k in the MC-2D-CDMA System

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As shown in Fig. 2, we assume that ψ_m has been estimated perfectly. We also suppose that no inter-frequency interference exists due to the design of orthogonal carriers, and spreading codes have been captured and tracked perfectly. So the sampled signals after matched filters in various carriers are

$$\begin{aligned} z_k^m &= N\alpha_m b_k + c_k(m)\alpha_m \sum_{i\neq k}\sum_{n=1}^{N} b_i c_i(m) a_i(n) a_k(n) + N_k^m \\ &= S_k^m + I_k^m + N_k^m \qquad m = 1,2,\cdots,M \end{aligned} \tag{4}$$

The final three components in (4) represent signal interested, MAI and Gaussian noise respectively. Considering the grouping method above and the orthogonal characteristic of WALSH codes, MAI can be simplified as

$$\begin{aligned} I_k^m &= c_k(m)\alpha_m \sum_{i\neq k} b_i c_i(m) \sum_{n=1}^{N} a_i(n) a_k(n) \\ &= c_k(m)\alpha_m \Bigg[\sum_{\substack{i\neq k \\ i\neq k \bmod N}} b_i c_i(m) \sum_{n=1}^{N} a_i(n) a_k(n) + \\ &\quad \sum_{\substack{i\neq k \\ i=k \bmod N}} b_i c_i(m) \sum_{n=1}^{N} a_i(n) a_k(n) \Bigg] \\ &= c_k(m)\alpha_m \sum_{\substack{i\neq k \\ i=k \bmod N}} b_i c_i(m) \sum_{n=1}^{N} a_i(n) a_k(n) \\ &= N c_k(m)\alpha_m \sum_{\substack{i\neq k \\ i=k \bmod N}} b_i c_i(m) \quad m = 1,2,\cdots,M \end{aligned} \tag{5}$$

So after diversity combination, the decision variable for b_k is

$$\begin{aligned} \hat{b}_k &= \sum_{m=1}^{M} \beta_m z_k^m \\ &= N b_k \sum_{m=1}^{M} \beta_m \alpha_m + \\ &\quad N \sum_{\substack{i\neq k \\ i=k \bmod N}} b_i \sum_{m=1}^{M} \beta_m \alpha_m c_k(m) c_i(m) + \sum_{m=1}^{M} \beta_m N_k^m \\ &= \sum_{m=1}^{M} \beta_m S_k^m + \sum_{m=1}^{M} \beta_m I_k^m + \sum_{m=1}^{M} \beta_m N_k^m \end{aligned} \tag{6}$$

β_m are gains for various branches when diversity combination. Different choosing of β_m forms different combination method.

III. Detection Methods

It is convenient to introduce a matrix-vector system model to describe various detection methods. Assuming

$$\boldsymbol{\beta} = [\beta_1 \quad \beta_2 \quad \cdots \quad \beta_M]^T,$$

$$\mathbf{S} = [S_k^1 \quad S_k^2 \quad \cdots \quad S_k^M]^T,$$

$$\mathbf{I} = [I_k^1 \quad I_k^2 \quad \cdots \quad I_k^M]^T,$$

$$\mathbf{N} = [N_k^1 \quad N_k^2 \quad \cdots \quad N_k^M]^T,$$

$$\mathbf{Z} = [z_k^1 \quad z_k^2 \quad \cdots \quad z_k^M]^T.$$

Then

$$\hat{b}_k = \boldsymbol{\beta}^T \mathbf{Z} = \boldsymbol{\beta}^T (\mathbf{S} + \mathbf{I} + \mathbf{N}). \tag{7}$$

Also assuming $\mathbf{Z} = \mathbf{H} b_k + \mathbf{V}$, then $\mathbf{V} = \mathbf{I} + \mathbf{N}$, $\mathbf{H} = N[\alpha_1 \quad \alpha_2 \quad \cdots \quad \alpha_M]^T$, and define correlated matrix $\mathbf{V}_z = \mathrm{E}[\mathbf{Z}\mathbf{Z}^T]$ and $\mathbf{V}_v = \mathrm{E}[\mathbf{V}\mathbf{V}^T]$.

A. Orthogonality Restoring Correlation (ORC)

ORC chooses the gains as $\beta_m = 1/\alpha_m$. Due to $\sum_{m=1}^{M} c_k(m) c_i(m) = 0, (i \neq k, i = k \bmod N)$, ORC delimitates MAI thoroughly. However, from (6), high gains will be given to those branches with small α_m, so the noise components in those branches are amplified.

B. Least Square Combination (LSC) or MRC

LSC minimizes the square sum of errors between the samples in each branch and their estimations based on decision variable. We can define the square sum of errors as

$$J(\hat{b}_k) = (\mathbf{Z} - \mathbf{H}\hat{b}_k)^T (\mathbf{Z} - \mathbf{H}\hat{b}_k). \tag{8}$$

Resolve $\dfrac{dJ(\hat{b}_k)}{\hat{b}_k} = -2\mathbf{H}^T(\mathbf{Z} - \mathbf{H}\hat{b}_k) = 0$, then

$$\boldsymbol{\beta}^T = (\mathbf{H}^T\mathbf{H})^{-1}\mathbf{H}^T. \tag{9}$$

Each component of this weighing vector is $\beta_m = \dfrac{\alpha_m}{N \sum_{i=1}^{M} \alpha_i^2}$, so it is equivalent with normalized Maximum Ratio Combination (MRC).

From (9), the estimation error of LSC is

$$e_{LS} = b_k - \hat{b}_k = (\mathbf{H}^T\mathbf{H})^{-1}\mathbf{H}^T(\mathbf{H}b_k - \mathbf{Z}) = -(\mathbf{H}^T\mathbf{H})^{-1}\mathbf{H}^T\mathbf{V}. \tag{10}$$

Then the variance of the error is

$$\mathrm{var}(e_{LS}) = (\mathbf{H}^T\mathbf{H})^{-1}\mathbf{H}^T\mathbf{V}_v\mathbf{H}(\mathbf{H}^T\mathbf{H})^{-1}. \tag{11}$$

When the interference in each branch is i.i.d. white Gaussian noise, LSC or MRC can conform to the maximum likelihood criteria. So in the case of singe user, in this paper that means only one user in each group or the number of users is not greater than *N*, LSC or MRC can achieve optimal anti-fading and anti-noise performance. However, when MAI exists, that means the number of users is greater than *N*, high gains will be given to those branches with great α_m, so the MAI in those branches are amplified. The MAI amplification effect of MRC degrades its performance greatly.

C. Weighted Least Square Combination (WLSC)

LSC treats the samples in each branch equally, but the MAI and fading make the strength of interference in various branches different, so the more acceptable method is Weighted Least Square criteria. That is, minimize

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$$J(\hat{b}_k) = (\mathbf{Z} - \mathbf{H}\hat{b}_k)^T \mathbf{W}(\mathbf{Z} - \mathbf{H}\hat{b}_k) . \quad (12)$$

Then $\hat{b}_k = (\mathbf{H}^T\mathbf{W}\mathbf{H})^{-1}\mathbf{H}^T\mathbf{W}\mathbf{Z}$,

and the estimation error of WLSC is

$$e_{WLS} = b_k - \hat{b}_k = -(\mathbf{H}^T\mathbf{W}\mathbf{H})^{-1}\mathbf{H}^T\mathbf{W}\mathbf{V} . \quad (13)$$

Then the variance of the error is

$$\mathrm{var}(e_{WLS}) = (\mathbf{H}^T\mathbf{W}\mathbf{H})^{-1}\mathbf{H}^T\mathbf{W}\mathbf{V}_v\mathbf{W}\mathbf{H}(\mathbf{H}^T\mathbf{W}\mathbf{H})^{-1} . \quad (14)$$

It is easy to prove that the weighting matrix minimizing the variance of the estimation error is $\mathbf{W} = \mathbf{V}_v^{-1}$, then

$$\boldsymbol{\beta}^T = (\mathbf{H}^T\mathbf{V}_v^{-1}\mathbf{H})^{-1}\mathbf{H}^T\mathbf{V}_v^{-1} . \quad (15)$$

$$\mathrm{var}(e_{WLS}) = (\mathbf{H}^T\mathbf{V}_v^{-1}\mathbf{H})^{-1} . \quad (16)$$

When the interference in each branched is uncorrelated, the meaning of Weighted Least Square is obvious. In this case $\mathbf{V}_v$ is diagonal, so the weighting factor in one branch is inverse proportional to the interference strength in this branch. When the number of users is very great and MAI can be approximated gaussian, WLSC conforms to the maximum likelihood criteria.

D. Minimum Mean Square Error Combination (MMSEC)

MMSEC minimizes the mean square error between the decision variable, $\hat{b}_k$, and signal interested, b_k. That is, β_m should minimize

$$\mathrm{E}(e^2_{MMSEC}) = \mathrm{E}[(b_k - \hat{b}_k)^2] = \mathrm{E}[(b_k - \boldsymbol{\beta}^T\mathbf{Z})^2] . \quad (17)$$

Compared with Least Square, MMSEC requires the knowledge about b_k. Assuming $p(b_k = 1) = p(b_k = -1) = \frac{1}{2}$, then

$\mathrm{E}(b_k) = 0$, $\mathrm{var}(b_k) = 1$, $\mathrm{E}(\mathbf{V}) = 0$,

$\mathrm{E}(b_k\mathbf{V}) = 0$, $\mathrm{cov}(b_k, \mathbf{Z}) = \mathbf{H}^T$。

So $$\boldsymbol{\beta}^T = \mathbf{H}^T\mathbf{V}_z^{-1} . \quad (18)$$

Then the variance of the estimation error

$$\mathrm{var}(e_{MMSEC}) = 1 - \mathbf{H}^T\mathbf{V}_z^{-1}\mathbf{H} . \quad (19)$$

E. Auxiliary Vector Combination (AVC)

The results of various combination methods above can be viewed as the projection of receiving vector, $\mathbf{Z}$, onto the weighting vector $\boldsymbol{\beta}$. Among them, MRC chooses the vector $\boldsymbol{\beta}_{MRC}$ with the same direction as signal vector $\mathbf{S}$, so MRC can achieve maximum signal projection. On the other hand, ORC chooses the vector $\boldsymbol{\beta}_{ORC}$ orthogonal to MAI vector, $\mathbf{I}$, so ORC can achieve minimum MAI projection. So, $\boldsymbol{\beta}_{ORC}$ can be an auxiliary vector[8] to strengthen the anti-MAI capability of MRC, which method can be called Auxiliary Vector Combination.

Assuming the normalized signal after ORC is

$$Z_{ORC} = b_k + I_{ORC} . \quad (20)$$

and the normalized signal after MRC is

$$Z_{MRC} = b_k + I_{MRC} . \quad (21)$$

Then one method combining ORC and MRC is the weighting sum, that is

$$Z = \lambda Z_{MRC} + (1-\lambda)Z_{ORC} = b_k + \lambda I_{MRC} + (1-\lambda)I_{ORC} . \quad (22)$$

Assuming $V_{ORC} = \mathrm{var}(I_{ORC})$, $V_{MRC} = \mathrm{var}(I_{MRC})$ and $V_{OM} = \mathrm{E}(I_{ORC}I_{MRC})$, then based on MMSE criteria, the optimal weighting factor is

$$\lambda = \frac{V_{ORC} - V_{OM}}{V_{ORC} + V_{MRC} - 2V_{OM}}, \qquad 1 - \lambda = \frac{V_{MRC} - V_{OM}}{V_{ORC} + V_{MRC} - 2V_{OM}} . \quad (23)$$

Then the variance of the estimation error

$$\mathrm{var}(e_{AVC}) = \frac{V_{ORC}V_{MRC} - V_{OM}^2}{V_{ORC} + V_{MRC} - 2V_{OM}} . \quad (24)$$

IV. Simulation Results

For testing the performance of the MC-2D-CDMA system and making a comparison among these combination methods, we do some simulation using SPW. In the simulation, we select $N = 16$ and $M = 4$; that is, the total spreading ratio is 64. We also assume the fading in each carrier is frequency non-selective and slow enough to estimate perfectly. For convenience, we assume the fading is independent, which can be implemented by making the carrier separation greater than the coherence bandwidth of the multi-path channel and interleaving the signal among various carriers.

Both WLSC and MMSEC need compute correlated matrix and its inverse matrix. This is a very unrealistic requirement for forward link in which the knowledge about other users' signal is usually unknown. Moreover, when the number of users is very great, the complexity is also unacceptable. In our simulation, we simplify the structure of WLSC and MMSEC [1] by assuming the correlated matrix is diagonal and achieve the correlated matrix by estimation. So the knowledge about noise and other users' signal is not necessary and the complexity is not very great. For AVC, we also achieve the variance of interference and crosscorrelation by estimation. So the structure of AVC is much simpler than that of WLSC and MMSEC, which need at least one estimator for one carrier. Then the simulation results are shown in Fig. 3 and Fig. 4. In these figures, the theoretical performances of DS-CDMA with 4-order MRC based on Gaussian approximation [9][10] are also shown.

As shown in the Fig. 3, MRC can minimize BER in the case of single user, in this paper that means the number of users is not greater than N. So the performance of MRC is same as that of DS-CDMA with 4-order diversity in the case of single user and obviously better than that of DS-CDMA in the case of 16 users due to MAI. In the case of single user, AVC and WLSC degenerate to MRC, so their performances are almost same. The performances of Equal Gain Combination (EGC) and MMSEC are slightly worse than that of MRC, but still much better than that of DS-CDMA.

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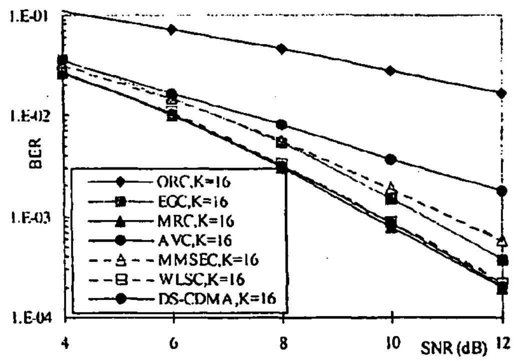

Fig. 3. BER Comparison in the case of single user

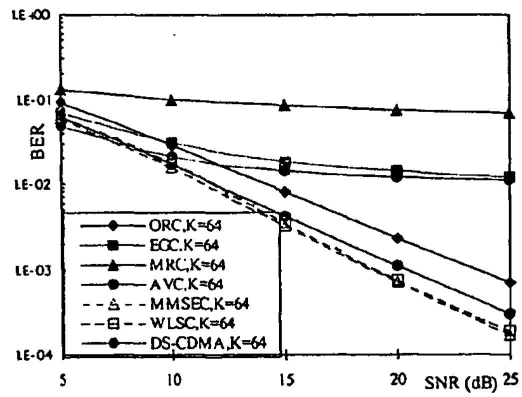

Fig. 4. BER Comparison in the case of full-load

As shown in the Fig. 4, due to MAI, the performances of MRC and EGC degrade greatly in the case of full-load, which means the number of users is equal to $M\times N$. It is also true for DS-CDMA because MAI is too great. On the other hand, the performances of WLSC and MMSEC degrade not so greatly and are far better than those of MRC and EGC. The performance of AVC approaches that of WLSC. Moreover, the performances of these new methods are all far better than that of DS-CDMA.

Moreover, the performance of ORC is not good, but not affected by the number of users. However, the performances of AVC and WLSC are equal to or better than that of conventional MRC and EGC in two cases. So AVC and WLSC are more suitable to the MC-2D-CDMA system, and AVC is also simple enough.

It is difficult to evaluate the performance of MC-CDMA on a fair point, because MC-CDMA system requires that the fading in each carrier is independent, which need wider frequency band if the same users number and spreading ratio are compared. So MC-CDMA system and the proposed system are used in different cases and performance comparison is hard to carry out.

V. Conclusion

In this paper, we present a novel MC-2D-CDMA system. Because of the full utilization of 2-Dimension spreading characteristic, the capability of multi-access is increased greatly and the frequency diversity provides anti-fading ability. For this system, we present and examine some combination methods. Among them, WLSC and MMSEC have better performance since they consider the signal and interference comprehensively. However they require the knowledge about other users' signal, which is unrealistic requirement for forward link, and their complexity increase greatly with the increase of the number of users and the number of carriers. We provide simpler approximating algorithm for them and the simulation results show the validity. For decreasing the complexity further, we present AVC, the combination of MRC and ORC. AVC is very simple and robust, and very suitable for forward link because it does not require any prior knowledge about other users and noise. The simulation results also declare that AVC can provide satisfied performance in any cases.

However, the further studies about inter-carrier interference, imperfect channel estimation, optimization of system parameters and detailed comparison with other systems are required. Moreover, the studies about better estimation of various correlation matrix and adaptive weighting are also worthwhile.

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